Dependable Distributed Computing for the International Telecommunication Union Regional Radio Conference RRC06

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Abstract

The International Telecommunication Union (ITU) Regional Radio Conference (RRC06) established in 2006 a new frequency plan for the introduction of digital broadcasting in European, African, Arab , CIS countries and Iran. The preparation of the plan involved complex calculations under short deadline and required dependable and efficient computing capability. The ITU designed and deployed in-situ a dedicated PC farm, in parallel to the European Organization for Nuclear Research (CERN) which provided and supported a system based on the EGEE Grid. The planning cycle at the RRC06 required a periodic execution in the order of 200,000 short jobs, using several hundreds of CPU hours, in a period of less than 12 hours. The nature of the problem required dynamic workload-balancing and low-latency access to the computing resources. We present the strategy and key technical choices that delivered a reliable service to the RRC06.

1 Introduction

The RRC06 is the second session of the Regional Radiocommunication Conference (RRC) for the planning of the digital terrestrial broadcasting service (in band III and IV/V) in European, African, Arab, CIS countries and Iran(Fig. 1). Delegations from 104 Member States of the International Telecommunication Union (ITU [1]) gathered in Geneva to negotiate the frequency plan, from the 15th of May to the 15th of June 2006.

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The preparation and the organization of this planning conference was managed by the ITU-R, the Radiocommunication Sector of the ITU. The RRC06 Final Acts [2] signed by the RRC06 participants constitute a new international agreement, which comprises the new frequency plan and the procedures for its modification.

Analogue broadcasting has been regulated since 1961 by the Stockholm Agreement in Europe (ST61) and since 1989 by the Geneva Agreement for Africa (GE89). The introduction of digital technologies called for a re-planning process in order to optimize the usage of those frequency bands. The new GE06 plan was designed for DVB-T (television) and T-DAB (radio) standards, but is flexible enough to accommodate future developments in digital broadcasting technologies.

The technical basis for this planning conference, such as the planning criteria and parameters, were established in the first session of the RRC (RRC04 [3]), which was held in Geneva in May 2004. During the RRC06 preparatory activities [4] it became evident that one component of the planning process, the compatibility analysis, was very CPU intensive. The goal of the compatibility analysis is to evaluate the interference between broadcasting requirements to identify those that can share the same channel. The analysis includes several parameters of the broadcasting requirements such as the geographic location, the signal strength and other technical characteristics.

The total capacity required for the compatibility analysis corresponds to several hundred CPU-days on a high-end 2006 PC. The compatibility analysis was performed in several iterations. For each iteration the RRC06 required the output of the compatibility analysis to be delivered within 12 hours. To support this requirement the compatibility analysis was split in a large number of parallel calculations. The ITU-R implemented a distributed client-server infrastructure and deployed at its headquarters a dedicated farm consisting of 84 high-end PCs. A distributed system based on the EGEE Grid (Enabling Grids for e-ScienE, [5]) and supported by the IT department of the European Organization for Nuclear Research (CERN) was deployed, which extended the computing capacity and improved dependability,

The nature of the problem required dynamic workload-balancing and low-latency access to the computing resources. This fundamental requirement was satisfied both by the ITU system, with its dedicated resources, and by the Grid system, by using high-level tools and appropriate customization of its infrastructure.

In this paper, we describe in section 2 the RRC06 planning process and in section 3 the computational aspects of the compatibility analysis. The implementation of the ITU system is presented in section 4. The Grid-based system

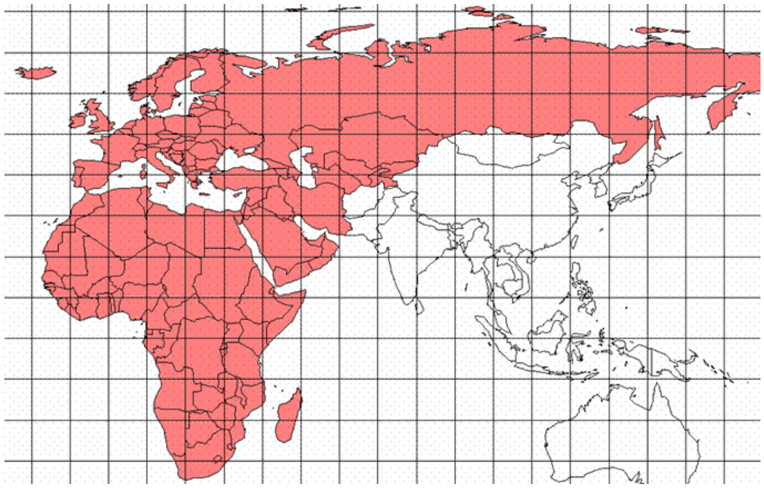

Figure 1. The extent of the geographical area regulated by the GE06 Agreement.

is analyzed in section 5 and the integration of the two systems is discussed in section 6.

2 The RRC06 planning process

The ITU Constitution [1] states that "the radio-frequency spectrum is a limited natural resource that must be used rationally, efficiently and economically, in conformity with the provisions of the Radio Regulations, so that countries or groups of countries may have equitable access to it"[6].

The Radio Regulations stipulate that "Member States undertake that in assigning frequencies to stations which are capable of causing harmful interference to the services rendered by the stations of another country, such assignments are to be made in accordance with the Table of Frequency Allocations (where the frequency blocks are allocated to different radiocommunication services and to different countries) and other provisions of these Regulations"[7].

2.1 Frequency Planning

A frequency plan represents a key mechanism for preserving the rights of all Member States in the context of equitable access to this limited resource. Regional Radiocommunication Conferences (RRC) establish agreements concerning a particular radiocommunication service in specified frequency bands

[1] The ITU Constitution, the ITU Convention and the Radio Regulations are the international treaties which define the rights and obligations of ITU Member States in the domain of the international management of the frequency spectrum.

amongst participating countries. The last RRC, the RRC06, established the frequency plans (digital and analogue) for terrestrial broadcasting service (in band III and IV/V) in European, African, Arab, CIS countries and Iran. The analogue broadcasting Plan will apply only during the transition period from analogue to digital broadcasting (up to the 17 June 2015 for most Member States). After this period the broadcasting in this band will be regulated only by the digital broadcasting Plan.

Some parts of the frequency bands to be planned at the RRC06 are shared between broadcasting and other primary services (like fixed and mobile services). The planning process therefore had to take into account all services which share those bands with equal rights to operate in an interference-free environment.

2.2 The input data

Member States submitted the input data to the ITU-R in the form of the so-called digital broadcasting requirements. The digital broadcasting requirements were notified as electronic files containing a set of administrative and technical parameters representing the broadcasting requirements. In addition to the digital broadcasting requirements (about 70K), the planning process had to take into account assignments to analogue television stations (about 95K) and assignments to other stations (about 10K). A fourth type of data, the so-called administrative declarations (a few million), declared that incompatibilities between digital broadcasting requirements, analogue television and other services stations may be ignored in the frequency synthesis procedure that followed the compatibilities analysis.

Radio communication services are described by administrative and technical parameters. For example, administrative parameters include the notifying administration, site name, geographic location, site altitude. Technical paramaters include the power levels, assigned frequency, network topology, etc.

The digital broadcasting requirements could be submitted at the RRC06 as T-DAB (radio) or DVB-T (television) standards. Suitable data elements were provided to accommodate expected development in digital broadcasting technologies. Reference Planning Configurations served as simplified models to represent the many system variants (which differ for example in data capacity and reception modes) of the requirements. Requirements were submitted as assignments (known location and transmitter features) or as allotments (only service area known). Allotments were modeled using Reference Networks (with different number, location and power of transmitters) to approximate real networks.

The RRC06 planning approach was based on the protection of service areas for assignments and allotments and used the statistical model outlined in the ITU-R Recommendation P1546-1[8] to model the signal propagation.

2.3 The planning process

The ITU-R performed two planning exercises after the RRC04 and prior to the RRC06. The first planning exercise was run in June 2005 and the second in February 2006. The second planning exercise established a draft plan which served as input to the RRC06.

The ITU-R and the European Broadcasting Union (EBU)[9] developed the RRC06-related software. The ITU-R developed the software for data-capture, data-validation and for the display of the input data and calculation results, while the EBU developed the planning software (compatibility analysis, plan synthesis and complementary analysis). The ITU-R was also responsible for running the planning software (partly on a distributed infrastructure), producing and delivering results in due time.

At the RRC06 the frequency plan was established in an iterative way, as outlined in Fig.2 The delegations engaged in bilateral and multilateral coordination and negotiation efforts which resulted in a new set of refined digital broadcasting requirements at the end of every week. Over the weekends the ITU-R performed the validation of the data and the compatibility analysis and synthesis calculations. The output of these calculations and the refined frequency plan were the input for the negotiations in subsequent week, with the last (fourth) iteration constituting the basis for the final frequency plan. In order to assist groups of negotiating Member States, partial calculations were performed for parts of the planning area in between two global iterations.

The compatibility analysis consisted of the calculation of the interference between digital broadcasting requirements and other primary services stations. For each requirement the compatibility assessment produces a list of incompatible requirements and a list of available channels. Three types of compatibility analyses were needed, for both UHF and VHF frequency bands: digital versus digital (d2dUHF and d2dVHF), digital versus other services (d2oUHF and d2oVHF) and other services versus digital (o2dUHF and o2dVHF).

These lists were the input to the plan synthesis process, which determined a suitable frequency for each requirement in order to avoid harmful interference and to maximize the number of requirements satisfied. The RRC06 decided to protect analogue broadcasting services during the implementation of the digital broadcasting requirements rather than during the establishment of the plan to maximize the number of requirements satisfied. For this reason each it-

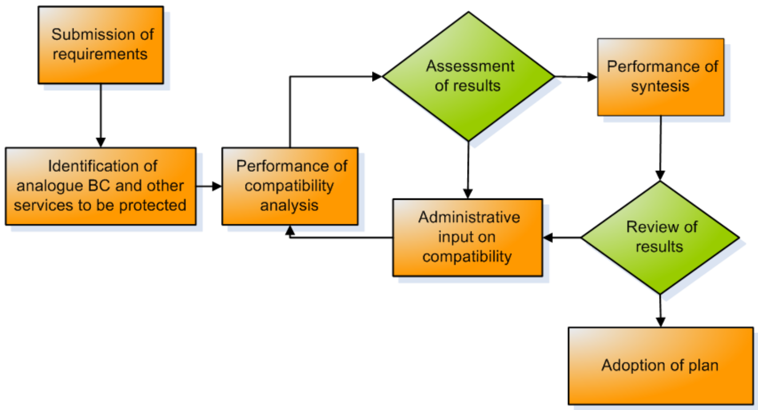

Figure 2. ITU negotiation workflow.

eration included a complementary analysis, which determined which analogue television assignments may suffer interference from the implementation of a given digital broadcasting assignment or allotment.

During pre-conference preparatory planning activities only 34% of requirements were satisfied. For the first iteration of the RRC06 the percentage increased to 64% (UHF) and 74% (VHF), to reach a satisfactory 93% (UHF) and 98% (VHF) for the final plan.

3 The computational challenge

The compatibility assessment is CPU-intensive. In the compatibility analyses each requirement must be run against all the others, for six different types of analysis (d2dUHF, d2dVHF, d2oUHF, d2oVHF, o2dUHF, o2dVHF). In this paper we use the term *atomic calculations* to refer to individual, indivisible calculations defined in compatibility analysis datasets. The term *task* refers a unit of work which corresponds to a set of atomic calculations. The term *job* is used in the context of Grid job submission only.

For the first planning exercise the atomic calculations were clustered in tasks of 100 for all types of analyses. With the limited resources available at that time, that exercise took about one week (elapsed time), for an integrated 90 CPU days.

The detailed study revealed an exponential distribution of the requirement processing time which spans almost three orders of magnitude (Fig. 3). The huge variation in running time depends, among other parameters, on the number of acceptable channels specified in the digital broadcasting requirement, the requirement type (assignment versus allotment), the network topology and signal propagation zones specific to the geographical area of the Member

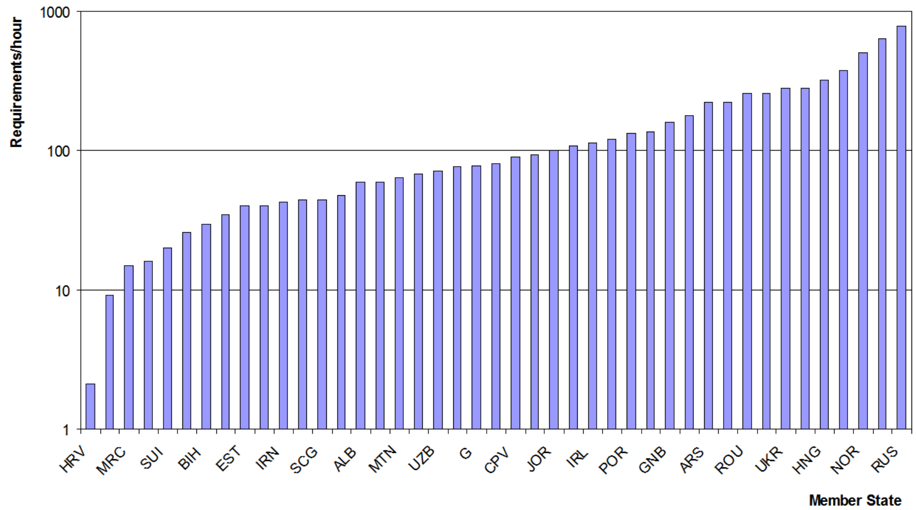

Figure 3. Distribution of the number of processed requirements per hour for the d2dUHF analysis as a function of the Member State. Data for the first planning exercise.

iteration	d2dUHF	d2dVHF	d2oUHF	d2oVHF	o2dUHF	o2dVHF
1	3(3)	5(5)	100(100)	100(100)	100(100)	100(100)
2	4(3)	4(10)	50(100)	50(100)	100(100)	100(100)
3	2(3)	2(5)	50(100)	50(100)	50(100)	50(100)
4	2(3)	2(10)	50(100)	50(100)	50(100)	50(100)

Table 1
Compatibility analysis granularity for the RRC06 iterations for Grid and ITU (in parenthesis) system.

State.

Further investigation showed that a complete static optimization of the load [2] was not possible due to the unpredictable nature of the data as the Member States could change their requirements before each RRC06 iteration. On the other hand, there was clearly a need to create smaller clusters for the most CPU demanding type of analysis d2dUHF and d2dVHF, minimizing the spread between the shortest and longest tasks. Table 1 shows the granularity chosen for the different types of analysis in the RRC06 iterations for the Grid and ITU systems. The granularity was adjusted manually in between the iterations. The load balancing was handled dynamically at runtime.

The workload for each compatibility analysis run at the RRC06 corresponded

[2] The static optimization of the load is an ability to a priori cluster the requirements, so that the execution time of each cluster is equal.

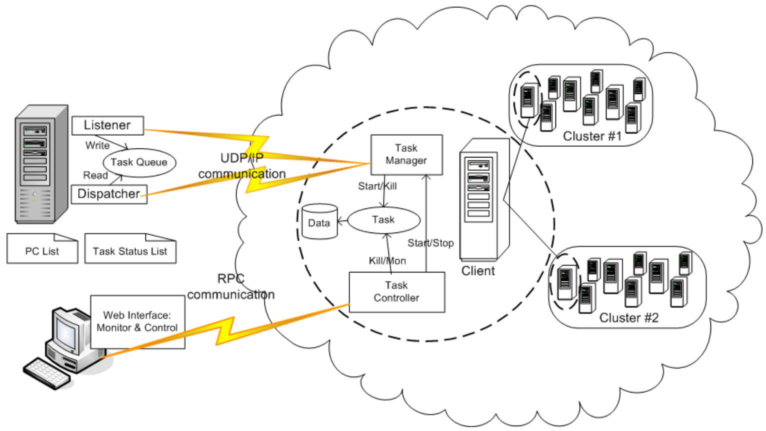

Figure 4. Architecture of the ITU dedicated system.

to some several hundred CPU hours. Additionally the workload was to be completed within a deadline of a few hours. The time constraints were critical: an hypothetical problem with timely delivery of analysis results could have resulted in a failure of international negotiations.

The total CPU demand decreased with each RRC06 iteration. Member States decreased the number of requirements and the number of acceptable channels for each requirement, reducing therefore the total workload at each analysis iteration. Finally, as the frequency plan was refined during successful negotiations between the Member States, the number of conflicting requirements also decreased. The CPU demands for the ITU and Grid systems is presented in the next sections.

4 ITU system

The ITU system consisted of a client-server distributed system running on a dedicated PC farm. The farm resources evolved in time. Initially it consisted of six high-end dedicated PCs complemented by some tens of ITU staff desktop PCs, available only overnight and during weekends. Using this configuration, the calculations for the first planning exercise required about one week, showing that the running time was an outstanding issue in preparation for the RRC06. The ITU-R therefore decided to buy a PC farm, which was deployed within ITU headquarters by the ITU Infrastructure Services department (ITU IS).In its final configuration at the RRC06 the farm was composed of 84 high-end dedicated 3.6 GHz hyper threading PCs. Accurate measurements showed that hyper threading permits to gain about 30% in computing time by running two tasks in parallel on one PC with respect to the situation when the same tasks are run sequentially.

To cope with redundancy and logistic issues (available space, power and cool-

Iteration	N_{calc}	N_{task}	t_{total}	$t_{clients}$
1	173K	26K	5.9h	621h
2	168K	23K	4.1h	463h
3	154K	23K	3.4h	300h
4	155K	21K	2.6h	205h

Table 2
Performance of the ITU system (84*2 simultaneous processes) during compatibily analysis calculations

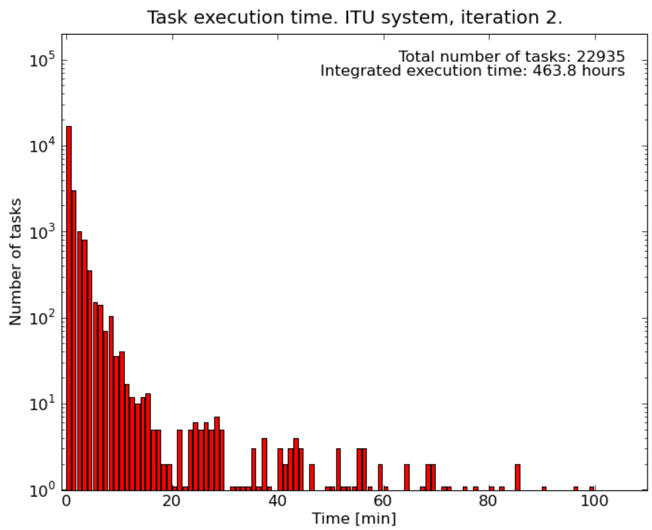

Figure 5. Distribution of the elapsed time for the ITU system during RRC06 iteration 2.

ing consideration), ITU-IS decided to deploy the farm into two separate clusters. The first cluster consisted of 47 PCs and was equipped with optical fibers and a 1Gb/s network switch, while the second cluster consisted of 37 PCs with a slower 200Mb/s network switch. This configuration did not significantly impact on the performance of the system.

The architecture layout is presented in Fig. 4. The system was implemented with Perl scripts installed as Windows services and a custom communication protocol based on UDP/IP. The UDP packets carried information on the executable to be run and on the relevant input parameters. In the reliable internal network of the ITU farm the packet loss was not a problem. The server implemented two Windows services, a Listener and a Dispatcher, responsible for task submission, task management and workload balancing. To cope with high-load, the TaskQueue file ensured asynchronous operation of the system and prevented packet lost. The system automatically managed the task status and resubmitted the ones which were not completed.

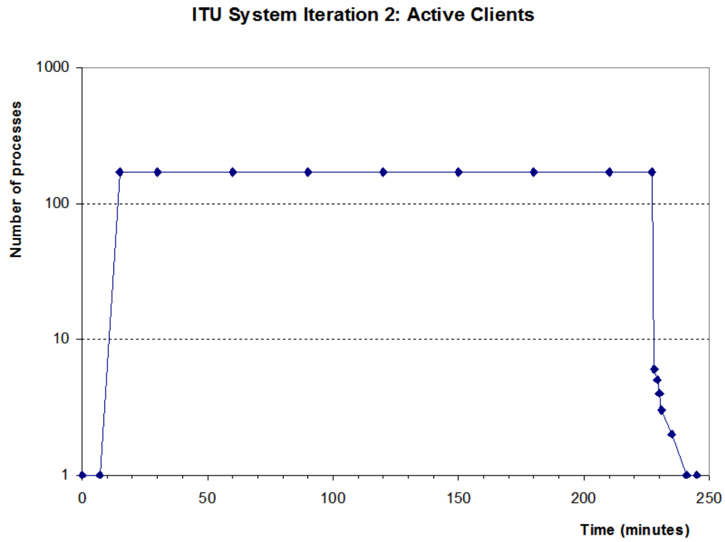

Figure 6. Number of running processes as a function of time during RRC06 iteration 2.

The clients implemented two Windows services, the TaskManager responsible for running tasks according to Dispatcher requests and the TaskController responsible for monitoring and control operations. A web application (implemented with ASP.NET and C#) running on a dedicated machine (WebInterface), provided monitoring and control interfaces to operate the system.

In the first phase, the client installation on non-dedicated resources (desktop PCs) was implemented using a MSI-compatible installation procedure managed by Windows Systems Management Server (SMS). In the dedicated farm, the software and data were deployed on a shared folder and copied directly to the client PCs. MD5 checksums were performed to insure data consistency. At system startup the server automatically triggered the software and data installation at the client.

The system supported 2*84 simultaneous tasks most of the time with negligible job loss. Software and data installation involved 350 MB to be deployed in 2*84 folders and took on average 15 minutes for the entire farm.

The performance of the ITU system is reported in Table 2, where the total workload of atomic calculations N_{calc}, the number of tasks N_{task}, the total time to complete the iteration t_{total} and the integrated elapsed time on the clients $t_{clients}$ are shown for each iteration. The distribution of the tasks processing time for the ITU system during iteration 2 of the RRC06 is shown in Fig. 5. The evolution of the number of running processes as a function of time during RRC06 iteration is shown in Fig. 6.This last figure illustrates interesting features of the ITU system: the dynamic load balancing (about 96% of the clients complete processing tasks practically at the same time) and limited

submission latency (about 15 minutes, the time necessary for the clients to download the latest version of software and data at server start-up).

Taking into consideration also the four runs of complementary analysis and the partial runs during multilateral negotiations, the ITU system at the RRC06 ran more than 180 thousand tasks for an overall integrated elapsed time of 4500 CPU/hours, i.e. more than half a CPU year.

5 Grid system

Enabling Grids for E-sciencE (EGEE) is a globally distributed system for large-scale batch job processing. At present it consists of around 300 sites in 50 countries and offers more than 80 thousand CPU cores and 20 PB of storage to 10 thousand users around the globe. EGEE is a multidisciplinary Grid, supporting users in both academia and business, in many areas of physics, biomedical applications, theoretical fundamental research and earth sciences. The largest user communities come from the High-Energy Physics, and in particular the experiments active at the CERN Large Hadron Collider (LHC).

The EGEE Grid has been designed and operated for non-interactive processing of very long jobs. A set of complex middleware services integrate computing farms and the batch queues into a single, globally distributed system. The access to the distributed resources is typically controlled by the fair-share mechanisms, ensuring usage of resources by groups of users according to predefined policies. In typical configurations a large number of users share individual computing resources across multiple Virtual Organizations (VOs)[3] This architecture is suitable for high-throughput computing but is not efficient for high-performance, short-deadline, dependable computing which is stipulated by the RRC06 compatibility analysis application.

In the EGEE Grid environment and on a short time-scale these requirements may only be implemented if high-level tools are used to control the job workload and the Grid infrastructure is appropriately customized.

5.1 The tools

To run RRC06 compatibility analysis application Ganga and DIANE tools were used.

[3] Virtual Organization is a group of users sharing the same resources. Members of one Virtual Organization may belong to different institutions.

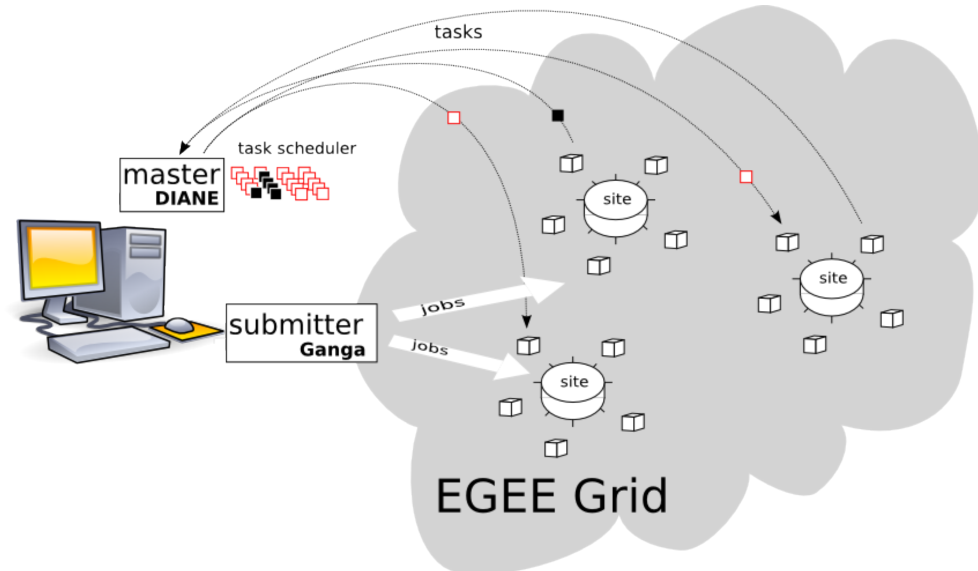

Figure 7. Overview of the Grid system based on Ganga/DIANE.

Ganga provides a uniform and flexible interface to submit, track and manipulate jobs [18]. DIANE is an agent-based job scheduler which provides fault-tolerant execution of jobs, dynamic workload-balancing and reduced overhead in accessing the computational resources [19].

The outline of the architecture is presented in Fig.7. Worker agents are submitted to the Grid and pull the tasks from the Master server which controls the distribution of the workload. The system is fault-tolerant and may run autonomously: a Worker agent which fails to complete the assigned calculations is replaced by another Worker agent. The overhead of scheduling the calculations is negligible in comparison with the overhead of classic Grid job submission. The system dynamically reacts to changing workload and provides dynamic load-balancing. The results of the compatibility analysis of the requirements are directly uploaded to the Master server. The implementation of the RRC06 system on the EGEE Grid was based on DIANE 1.5.0 and Ganga 4.1.

The input data, including the specification of the digital broadcasting requirements and the tuned compatibility analysis application, were distributed to the collaborating Grid sites shortly before the analysis was launched. The 100MB installation package was deployed into the directory mounted on a shared file system accessible by all worker nodes of a collaborating Grid site (so called "software areas"). The installation was managed by separate grid jobs running with the credentials of the VO manager and using MD5 check-sums to assure consistency of the installation tarballs. The installation was automated and the installation jobs checked periodically to download the installation packages available in a central repository at CERN. This allowed to automatically distribute the new installation packages in 15 minutes after the ITU-R made

iteration	N_{calc}	N_{task}	t_{total}	t_{worker}	N_{worker}	r_{fail}
1	243K	26K	6h40m	425h	190	$<3\,\mathrm{e}{-4}$
2	237K	23K	6h30m	332h	125	$4\,\mathrm{e}{-5}$
3	224K	40K	1h35m	192h	210	0
4	218K	39K	1h5m	151h	320	0

Table 3
Summary of RRC06 compatibility analysis iterations.

them available.

The ITU personnel updated the software packages with 2 hours' notice. In this time window the grid system had to be up and ready to start the computation at full speed, as soon as the update was available.

5.2 The infrastructure

The access to the computing resources on the Grid for the RRC06 use was implemented using the GEAR Virtual Organization (vo.gear.cern.ch). The CPU demand for RRC06 was much smaller than typical Grid applications which require huge throughput over very long periods of time. However, conversely to many other Grid applications, availability of resources within well-defined and strict time constraints was critical. Therefore a number of high-availability centres in the EGEE Grid [4] were involved. The resources at these centres were not dedicated to the RRC06 activity, however the job priority parameters were adjusted during short periods of intensive processing of the RRC06 compatibility analysis (the weekends between the major conference iterations). On average 300 CPUs were observed to be available at all times with occasional peaks of c.a. 600 CPUs.

Redundant deployment of key services, such as the Master servers, Grid User Interfaces and Resource Brokers [15] allowed for fail-over in case of problems. For storing the application output the AFS and local filesystem were used simultaneously.

5.3 Analysis of the system

The summary of RRC06 iterations is presented in Table 3. For each analysis iteration the total workload consisted of N_{calc} atomic calculations. The

[4] CERN, CNAF+few other sites(I), PIC(E), DESY(D), MSU(RU) , CYFRONET(PL)

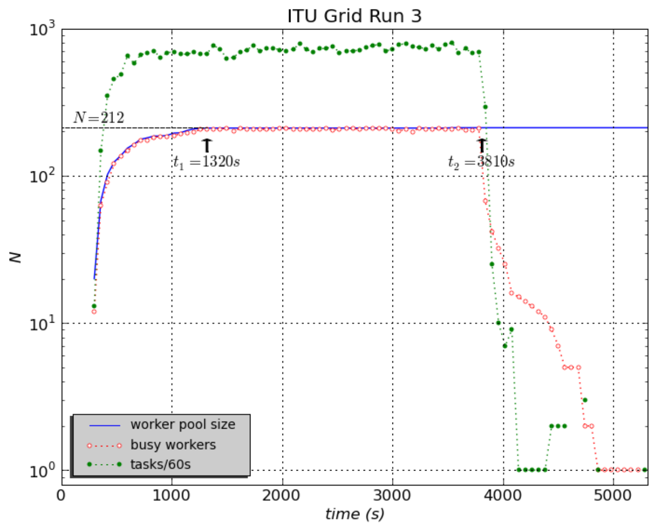

Figure 8. Run 3 workload. Resolution=60s.

calculations were executed in bunches according to previously defined static clustering (section 3). The N_{task} tasks were distributed dynamically to the N_{worker} Worker agents. The Worker agents were submitted as *jobs* and executed on the Grid worker nodes. t_{total} is the makespan or the total time to complete the compatibility analysis. t_{worker} is the integrated elapsed time on the worker nodes. r_{fail} is the reliability of the system and corresponds to the number of failed tasks which could not automatically recover. With fewer than 10 lost tasks in run 1 and one lost task in run 2 the reliability of the system exceeded by few orders of magnitude the reliability of the Grid infrastructure.

Contrary to the ITU system which used a fixed set of resources, in the Grid resources are dynamic: a different set of worker nodes is used at each iteration. The worker node characteristics such as the CPU and memory also show large variations. Therefore a direct comparison of t_{total} and t_{worker} parameters between ITU and Grid runs is not possible.

The efficiency of the system depends on the Grid job submission latency, efficiency of task scheduling and workload balancing. Fig. 8,9 show the workload distribution for selected runs. N_w worker agents are submitted at $t_0 = 0$. In the submission phase, $t < t_1$, the throughput of the system is limited by the submission latency. As the pool of worker nodes increases the target of N_w workers is reached at time t_1. In the main processing phase, $t_1 < t < t_2$, the pool of worker nodes remains stable and the system throughput mainly depends on the efficiency of scheduling. At time t_2 the number of remaining tasks becomes smaller than the number of processors in the pool. In this phase the execution time is dominated by the workload-balancing effects from few slowest tasks.

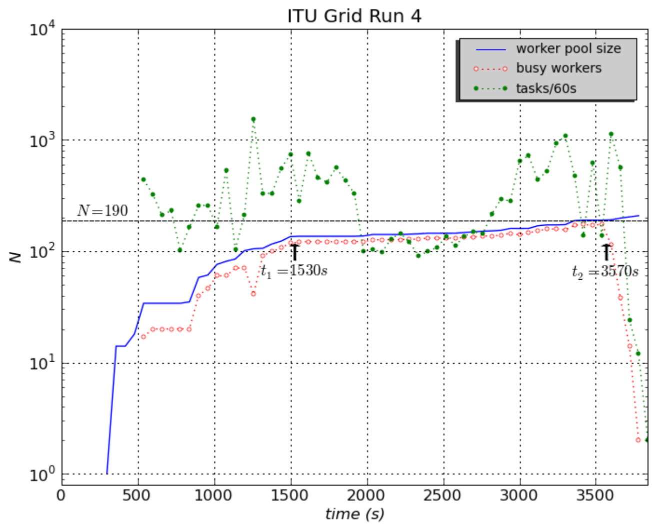

Figure 9. Run 4 workload. Resolution=60s. The point t_1 was selected arbitrarily. In run 4 two parallel master servers were used and this figure corresponds to one of the masters and half of the total workload.

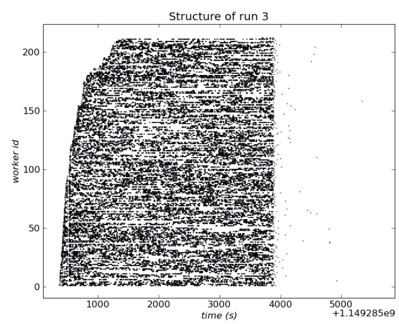

Figure 10. Run 3 profile.

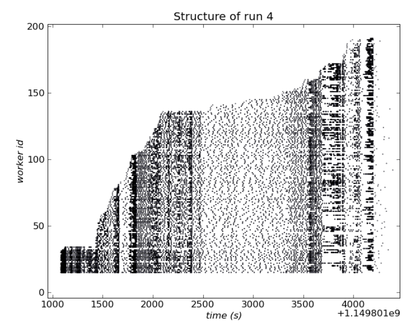

Figure 11. Run 4 profile.

The number of available worker nodes may vary significantly in the Grid from one run to another. The contribution of the job submission latency to the total execution time may be approximated by the area between the target line and the worker pool size curve. In run 3 the latency of job submission corresponded to 12% of the total execution time, whereas in run 4 it corresponded to 48%: 33% in the submission phase and 15% in the main processing phase.

The integrated difference between the worker pool size and the number of busy workers corresponds to the scheduling overhead. This overhead includes the network latency and throughput as well as the task handling efficiency of the master server. In run 3 the scheduling overhead in the submission and processing phases corresponded to 2-3%. In run 4 the 30% scheduling overhead in the submission phase was observed and 10% in the processing phase.

The unbalanced execution of the slowest tasks in the last phase contributes 26% of the total execution time in run 3 and to 5% in run 4. In this phase the utilization of available resources was very low, 5% in run 3 and 20% in run 4. The majority of the workers in the pool remained idle while the few remaining tasks were being finished.

The striking difference of scheduling and workload-balancing efficiency between runs 3 and 4 may be explained by the task scheduling order which reflects the internal input data structure. The run profile plots are shown in Fig. 10, 11. Point (t,w) in the run profile represents a task completed by worker w at time t. In run 4 the tasks are drawn directly from the input data in the natural order and clusters of very short tasks created a very high load on the server. The long tasks were processed in the middle of the run and did not affect the overall load-balancing. In run 3 the tasks were selected in a random order by the scheduler. The momentary load on the server was reduced. The tasks were scheduled more uniformly across the entire run. There were a few long tasks at the end of the run that resulted in poor load-balancing.

The intrinsic job submission latency in the Grid prevents the running of a large number of short jobs in a short time, unless user-level tools such as DIANE are used. For RRC06 using DIANE allowed to reduce the Grid overheads and provided efficient management of a large number of tasks. Additionally a runtime workload balancing allowed to evenly distribute a workload without precise, a priori knowledge of the task execution times in the dataset. The overhead reduction and workload balancing were the crucial factors of the successful usage of the Grid for the RRC06.

6 System Integration

The Grid and ITU systems were integrated at the monitoring level using the MonALISA framework (Monitoring Agents in A Large Integrated Services Architecture, developed by Caltech University [20]). MonALISA provides a set of pluggable distributed services for monitoring, control, management and global optimization for large scale distributed systems.

To collect and combine monitoring information from both ITU and Grid systems, the following software components were deployed: instances of MonALISA collector service, web-enabled data visualization repository and custom ApMon monitoring sensors on worker nodes (Fig. 12).ApMon, the monitoring API, allows to send fine-grained custom monitoring parameters into the MonALISA collector service. The ApMon uses UDP datagrams to transport the XDR-encoded information [21] and includes a sequence number to verify the integrity of all monitoring reports. In addition, ApMon provides out-of-the-

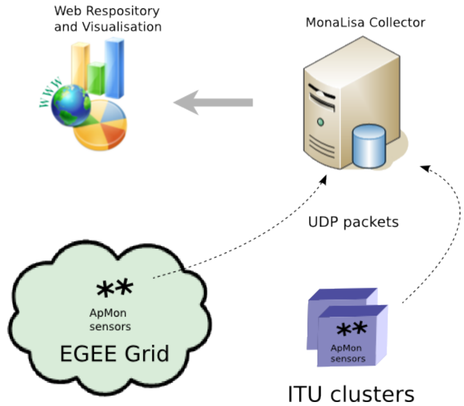

Figure 12. System integration via Mona Lisa monitoring.

box system monitoring of the host, including usage of system resources such as memory or CPU. Monitoring parameters of ApMon, such as monitoring frequency and collector destination, may be dynamically configured by remote services. ApMon implementations are provided for different programming languages, including C, C++, Java, Perl and Python. The cross-language support has proven to be useful in the case of RRC06 as the ITU system was built in Perl while the Grid used Python.

Using pluggable modules, the MonALISA collector has been customized to aggregate fine-grained data from Grid worker nodes and ITU farm nodes to produce in real-time, higher level reports and charts. Fig.13 shows the total workload executed by ITU clusters and the EGEE sites. The ITU clusters are reported as `RRC06-1.itu.org` and `RRC06-2.itu.org`.

The complementary usage of Grid Unix-based and Windows-based resources for numerical computations, required compilation of application software on both platforms and verification of output in terms of numerical accuracy.

7 Conclusions and Outlook

The dual system presented in this paper contributed to the success of the RRC06 Conference which resulted in a new international treaty.

Seamless access to resources from Grid and corporate infrastructures demonstrated in this paper may be beneficial for other user communities. A typical use-case could include dedicated in-situ resources for fast response and Grid resources when facing peak demand. In such a scenario the Grid could provide a competitive alternative to traditional procurement of resources. At RRC06 the Grid delivered dependable peak capacity to an organization which normally does not require a large permanent computing infrastructure. The Grid

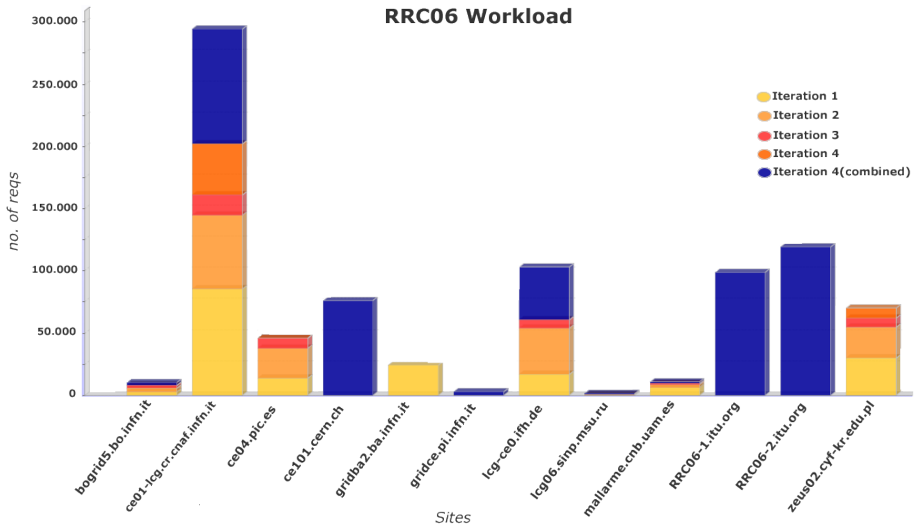

Figure 13. Total workload executed in Grid and ITU clusters.

was successfully used in a new area to provide a dependable just-in-time service. ITU personnel needed limited support and training to adopt the Grid technology for RRC06. This demonstrates the maturity of Grid technology for usage in new scientific communities and technical activities.

The outcome of RRC06 was the GE06 frequency plan which is a part of an international agreement. Modifications to the GE06 Plan may require a coordination examination to determine Member States potentially affected. To bring into use a new broadcasting station a conformity examination is required to verify that the proposed implementation does not cause more interference than foreseen by the GE06 Plan. Both examinations may require intensive calculations. In addition, some Member States have already expressed the possible need for re-planning parts of the GE06 planned bands, a process which would imply a similar (smaller scale) approach to the one adopted at the RRC06.

In order to prepare for future events which may require even more computing capabilities than the RRC06, paradigms such as Cloud computing could be investigated, where dynamically scalable resources are provided as a service over the Internet. A system integrating local, grid and cloud resources would allow Member States to submit via an existing ITU web portal time-consuming calculation requests and, at the back-end, to schedule and execute jobs transparently on the integrated infrastructure. Such a pilot project could be a continuation of the system accomplished for the RRC06 and a potential area of future collaboration between ITU and CERN.

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